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SOIL FREEZING DETERMINED WITH FOUR TYPES OF WATER-FILLED TUBES

Norbert V. DeByle[1]

ABSTRACT

During two winters (1966-67 and 1967-68) periodic determinations were made of soil temperatures and ice column depths in four types of tubes inserted in the soil at three sites in northern Utah. The 0°C. isotherm varied in depth from the surface to 21 inches at lower elevation sites in Logan and to 41 inches on an exposed mountain ridge at 8,870 feet elevation. Steel tubing (1.55-inch inside diameter), commonly used as access tubes for neutron probes used in soil water measurements, proved to be as good as steel or plastic pipe as casings for water-filled frost meter tubes.

The depth, persistence, extent, and nature of soil frost are of biotic and hydrologic importance. The nature of soil frost can be determined only through laborious methods, such as digging or probing (Stoeckeler and Thames 1957). However, any temperature-sensing device can be installed and left in place for several years to sample depth, persistence, and extent of freezing temperatures in the soil. Thermistors or electrical soil moisture resistance blocks, buried at specified depths in the soil profile, are commonly used.

Frost meters, based on the freezing of a contained aqueous solution held in the soil, have been tested and used, too. Sartz (1967) checked one of these meters and concluded that it was not satisfactory. An even simpler instrument, the Danilin soil-freezing meter, a direct-reading, tube-type gage, has been used in the Soviet Union and is reported to be reasonably accurate (Molga 1962, pp. 91-92). However, Kapotov (1968) feels it may overestimate frost depth. Modifications of the Danilin meter have been made and tested on this continent. For example, Patric and Fridley (1969) used a water-filled plastic tube encased in a copper tube buried vertically in the soil.

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[1]Plant Ecologist, stationed in Logan, Utah, at the Forestry Sciences Laboratory, which is maintained in cooperation with Utah State University. The author acknowledges the assistance of E. Arlo Richardson, ESSA Weather Bureau, in instrumenting this research.

Currently, similar devices are being extensively tested by the U.S. Army Cold Regions Research and Engineering Laboratory (Brown and Rickard 1968) and by the North Central Forest Experiment Station (Harris 1970). Basically, they are working with sand- or liquid-filled tubes of transparent plastic encased in plastic tubes. They have found a dilute aqueous solution of fluorescein dye in a sand-filled tube to be most reliable, accurate, and easy to read. The fluorescein separates from the water as it freezes, leaving a distinct color change between the liquid and solid phases.

The tests I report here were made with modified Danilin frost meters filled with water. At the time, I was not aware that dilute aqueous dye solutions in sand might be better than distilled water columns; consequently, this paper can best serve as a comparison of different types of outer casings for frost tubes.

METHODS

Four frost meters and a stack of thermistors were installed at each of three sites before the soil froze in 1966. Two sites were in Logan, Utah, adjacent to one another on very stony alluvium. The surface foot of soil on these sites differed; on one it was black loam, on the other, sand. The third site was on a windswept mountain ridge at 8,870 feet elevation near Farmington, Utah.

A pit, approximately 3 by 5 feet by 6 feet deep, was dug at each site. The following casings were positioned vertically at maximum distances from each other: a 5/8-inch (inside diameter) galvanized iron pipe, a 5/8-inch black iron pipe, a 5/8-inch black plastic pipe, and a 1.55-inch black steel soil moisture access tube. The bottoms of the pipes and the access tube were sealed. Thermistors, calibrated through the range of soil temperatures expected, were installed at least a foot lateral distance from any casing and at selected depths (2, 6, 12, 18, 24, and 36 inches in Logan; plus 42, 54, and 66 inches on the mountain). After the soil had been packed back into the pit, the protruding casings were painted white to minimize absorption of solar radiation. These protruding ends varied in length from 8 to 50 inches, depending upon the site and the year.

The access casings for frost meters in Logan extended 50 inches above the sandy soil and 18 inches above the loam soil during the first winter. The 50-inch extensions were shortened to 8 inches during the second winter. Snow was removed from the Logan sites the first winter but allowed to accumulate during the second. Casings extended 24 inches above the soil throughout both winters on the mountain site; so, depending on snow depth, 5 to 24 inches of tubing was exposed to solar radiation during the season of soil freezing.

The outside diameter of the frost meter, a 4-foot length of clear, flexible, plastic tubing, measured 7/16 inch in the small casings and $1\frac{1}{4}$ inches in the soil moisture access tubes. Each meter was fabricated as shown in figure 1. Plastic plugs were glued into both ends of the tube. A string was run through the tube, left fairly slack, and glued to these plugs. The string effectively held the ice column at the depth of its formation. The tube was filled with distilled water to within 6 inches of its top; the upper air space allowed for expansion or contraction of water volume due to temperature changes or to freezing. The tube was graduated from the water level downward. The top of the water column was placed at ground level by adjusting the length of chain between the pipe cap and the top of the tube. A stiff wire would have been better than the chain; it would have allowed the frost meter to be pushed to the proper depth against the friction on the inside of the casing.

Periodic readings were taken at each site during the winters of 1966-67 and 1967-68 (fig. 2). Soil temperatures (from thermistor readings) and depth of frost (indicated by depth of ice column in the frost meters) were recorded. The depth of freezing temperatures (0° C. isotherm) was estimated by interpolation of readings between thermistors.

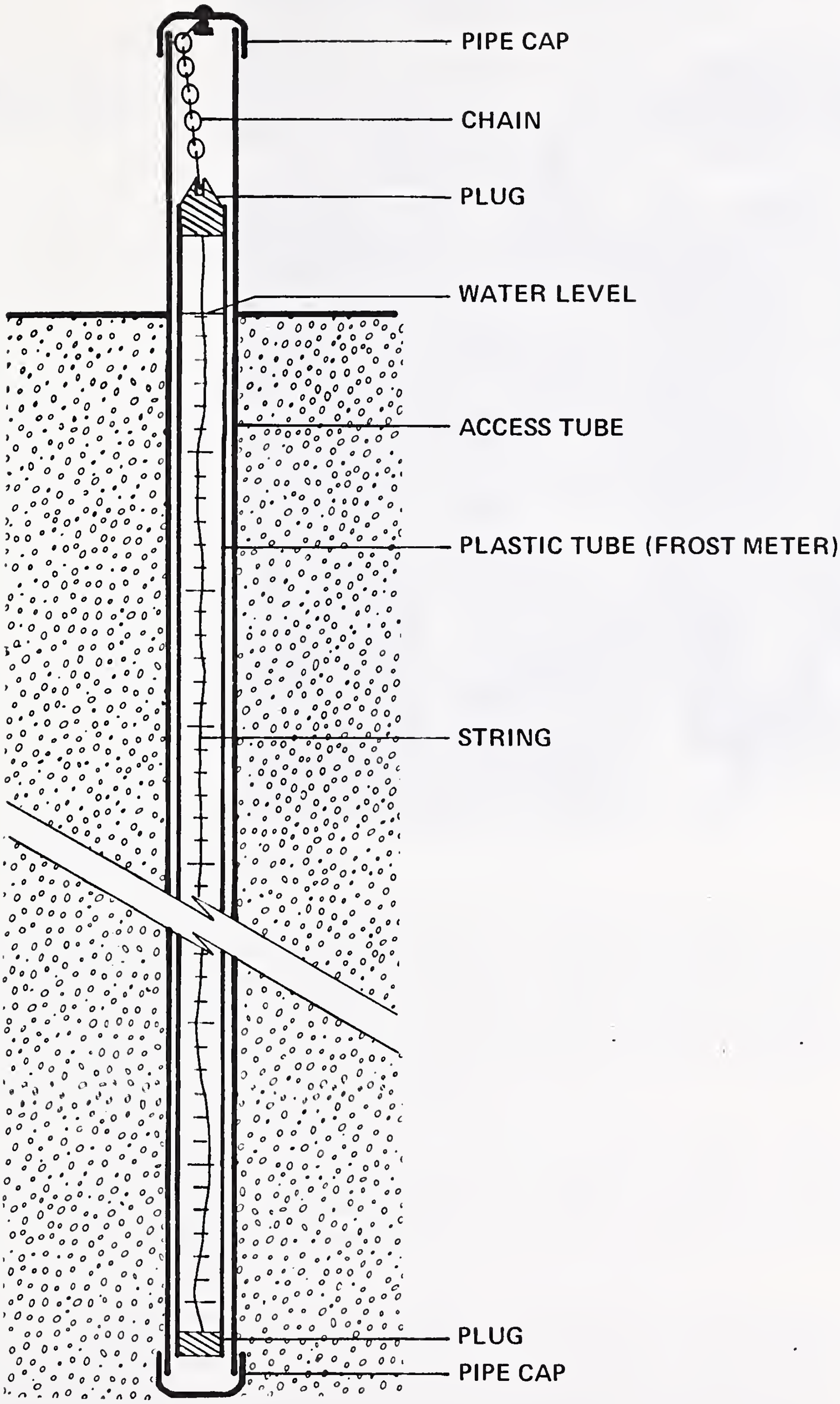
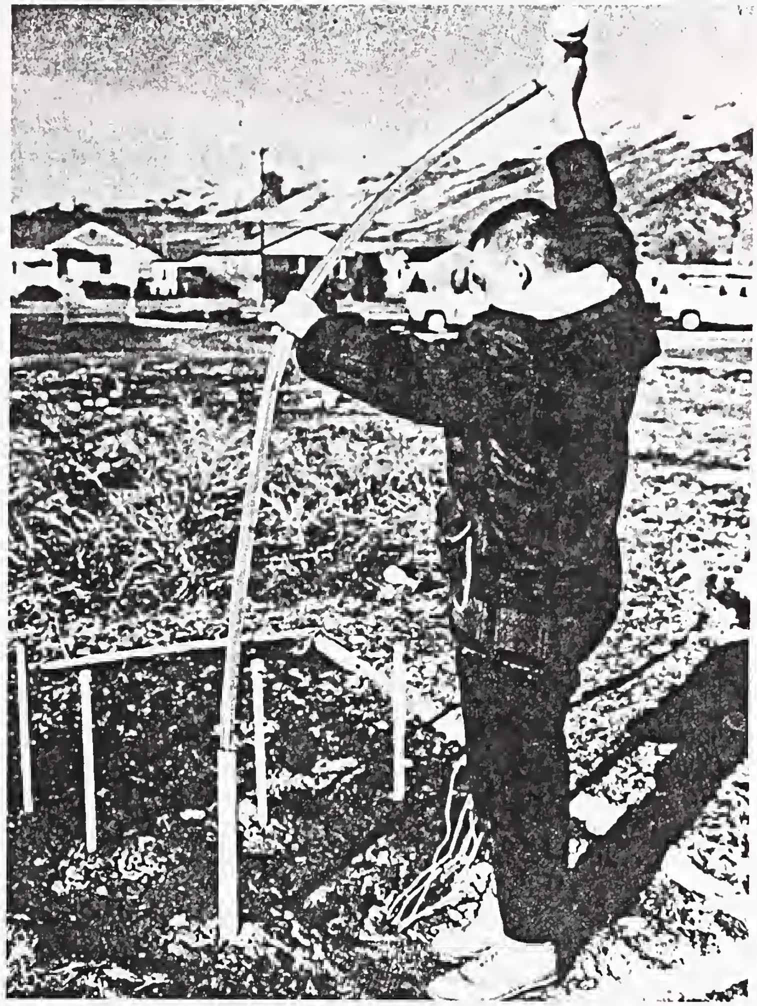


Figure 1.--Modified Danilin frost meter.

Figure 2.--Gathering data from a frost-meter site in Logan.



RESULTS

During the first winter, when snow was removed from the Logan sites, freezing temperatures on January 11 extended to their maximum depths: 10.3 and 17.5 inches beneath loam and sandy soils, respectively. At that time, there were freezing temperatures to at least the 30-inch depth on the mountain ridge, where snow depths seldom exceeded a foot. The maximum freezing depth, 40.6 inches, was recorded March 7 on the mountain. Midwinter mild weather thawed the soil in Logan, and all thermistor readings after January 16 were above 0° C. The 0° C. isotherm was at the 18-inch depth on the mountain April 18, and readings were all above freezing by May 16.

During the second winter, maximum freezing temperatures in Logan extended to 18.0 and 21.4 inches in the loam and sandy soils, respectively. These measurements were made on January 23 under 4 inches of snow. Only one reading was taken on the mountain that winter; on February 1, freezing temperatures extended 24.8 inches into the soil, which was then buried under a 16-inch snowpack.

Wide differences in exposed casing lengths produced no detectable effect on ice depth in frost tubes. Apparently, tubes, painted white and as much as 50 inches long, conduct an insignificant net amount of solar radiation into the frozen soil. Unfortunately, limited data preclude a thorough statistical analysis of this important feature. However, this observation is supported by earlier research, in which access tubes were found to have no influence on soil temperatures under the severe winter climate of Montana (Dickey, Ferguson, and Brown 1964).

Several linear regression analyses were run to determine relationships between depth of ice in the various types of frost meter tubes and depth of the 0° C. isotherm in the soil. One analysis involved all 72 observations; the ice column depth was compared with the independent, concomitant depth of the 0° C. isotherm in the soil at the respective site. The equation was $\hat{Y} = 5.3579 + 1.0052X$, with an r^2 of 0.65. This relationship was highly significant; some 65 percent of the variance in ice column depth could be explained by soil temperature. In another analysis, 20 observations of ice depth in meters encased in soil moisture access tubes were compared to concomitant 0° C. isotherm determinations. The resultant equation was $\hat{Y} = 6.7836 + 0.9594X$, with an r^2 of 0.60.

Both analyses revealed a major disadvantage in the use of water-filled frost tubes. The spread of data, indicated by r^2 values of 0.65 and 0.60, was caused by a lag in frost meter response to soil temperature changes. Ice remained in the meters during thaw periods for some time after the soil temperature exceeded 0° C. For example, the 0° C. soil isotherm on the mountain had reached 18 inches April 18, but some 41 inches of ice remained in the meter within the soil moisture access tube. By May 16, there were still 36 inches of ice in that meter, although soil was entirely above freezing. In Logan, a similar lag existed during the midwinter thaw; some 14 inches of ice remained in meters of the above type after soil thermistors gave above-freezing readings.

There is an intolerable lag in response from these frost meters, at least during the thaw season. Coarse-textured, well-drained soils warm and thaw well before ice melts in such meters. But, before the soil moisture access tubes are condemned as casings for frost meters, let's compare them to the other casings.

The depths of ice in the frost meters encased in access tubes (dependent variable) were compared to depths of ice in the frost meters encased in plastic pipes on the same site at the same time (fig. 3). This regression yielded an r^2 value of 0.98. Obviously, the access tube casing was just as good as the smaller-diameter, plastic tube casing for the modified Danilin frost meter. If one is rejected as being unsatisfactory for accurate soil-frost measurements, both must be rejected.

Three other regressions compared the different casings. In the first, galvanized iron pipe (dependent) was compared to black iron pipe (independent). Despite the similarity in materials, especially when both were painted white, the r^2 value was not as great as when access tubes and plastic pipes were compared. Fourteen observations were used; they produced an r^2 of 0.92 and the following regression equation:

$$\hat{Y} = -0.2425 + 0.9495X.$$

In the next regression, black iron pipe (dependent) was compared to plastic pipe (independent). Twenty-one observations were used. The r^2 value was 0.97 and the equation:

$$\hat{Y} = 0.2115 + 1.0274X.$$

Finally, access tubing (dependent) was compared with black iron pipe (independent). Twenty observations resulted in an r^2 of 0.95 and the following equation:

$$\hat{Y} = 1.219 + 0.9366X.$$

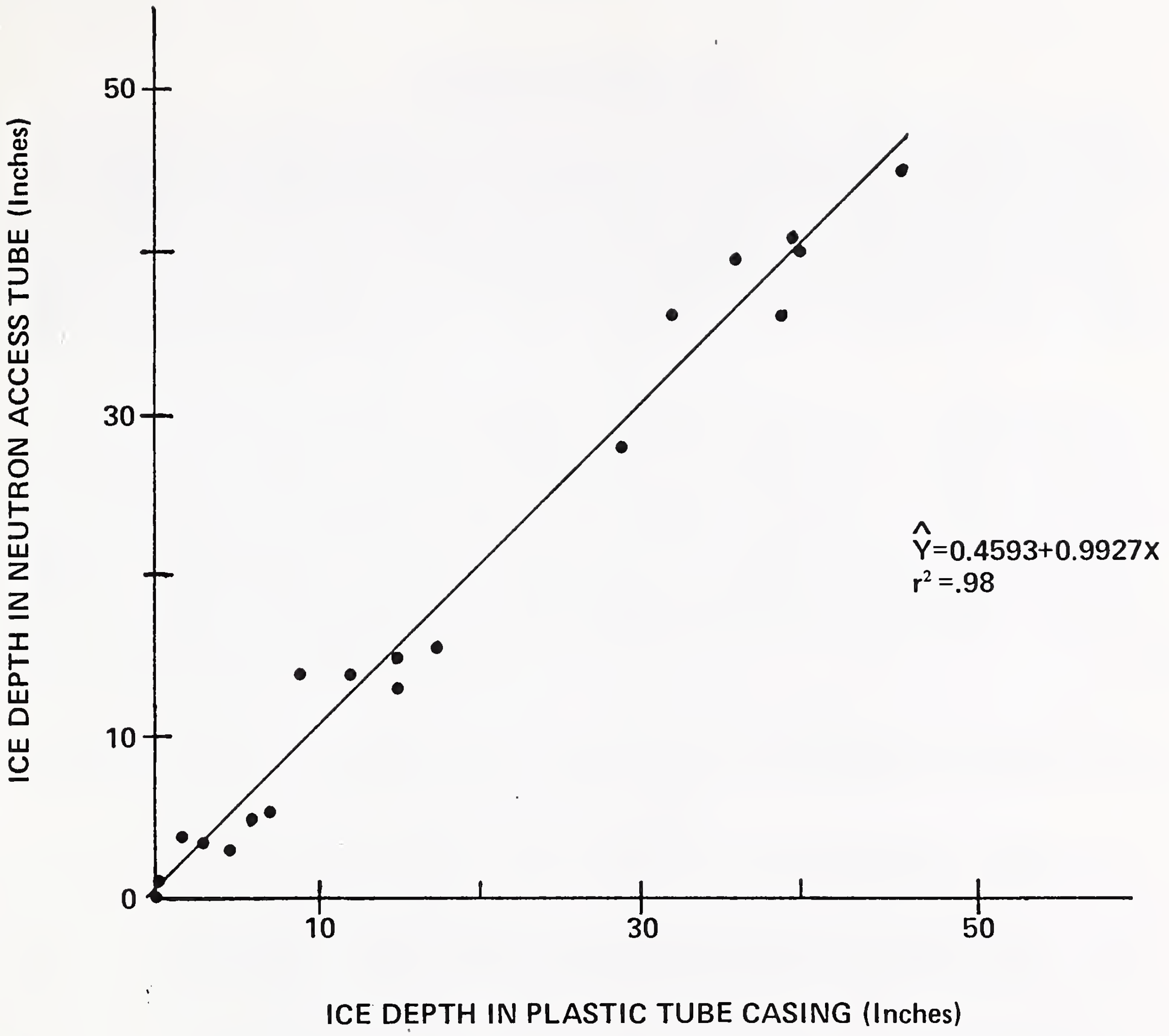


Figure 3.--Regression of data from frost meters with neutron access tube casings on data from meters with plastic pipe casings.

DISCUSSION AND CONCLUSIONS

Rather simple, easy-to-read frost meters can be used as an index of soil freezing. All modifications tested had about the same degree of accuracy; comparisons among them resulted in r^2 values that ranged from 0.92 to 0.98. However, the accuracy of all could be challenged when these data were compared to soil thermistor data and an r^2 value of only 0.65 resulted. The lag time in frost-meter response, especially during melt periods, accounted for much of the inaccuracy. Perhaps, the large quantity of water or ice in the frost meter tube plus the insulating effect of the air-space in its casing caused this delayed response. In any event, it was no worse in casings of soil moisture access tubes than in any other type of casing tested.

So, if frost meter tubes are accepted as adequate for soil frost measurements--as the sand-filled modifications being developed by Brown and Rickard (1968) perhaps are--it may make little difference whether these tubes are inserted in specially installed plastic casings, in pipe, or in already installed soil moisture access tubes. Certainly, if soil moisture access tubes can be used as acceptable casings for frost meters, their usefulness can be doubled. One installation could be utilized for soil water measurements in the frost-free season and for soil frost measurements during the remainder of the year. On sites that have appreciable snowpacks, plastic extensions probably would have to be added to the access tubes in the autumn when meters are inserted. These extensions and the frost meters could easily be removed in the spring prior to taking soil water readings with the neutron probe.

This proposed dual use (soil water plus soil frost metering) of an installation would not only save installation costs in many cases, but have other advantages as well:

1.--Neither use is destructive to the site;

2.--The thawing of frost in the spring may indicate the need to begin soil water readings at that site;

3.--Soil profile characteristics, usually determined at sites of soil water measurements, can also be used to explain soil frost conditions;

4.--If concomitant data on soil frost and soil water content are desired, the same microsites (holes) may be used; merely remove the frost meter from the access tube casing, read it, take the neutron soil water readings at the desired depths in the hole, and replace the meter. This would contribute to the ease and precision of some research, such as that conducted by Sartz (1969a, 1969b).

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